

Physical validation: the contribution of the Bonn University and Research Center Jülich

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Bonn

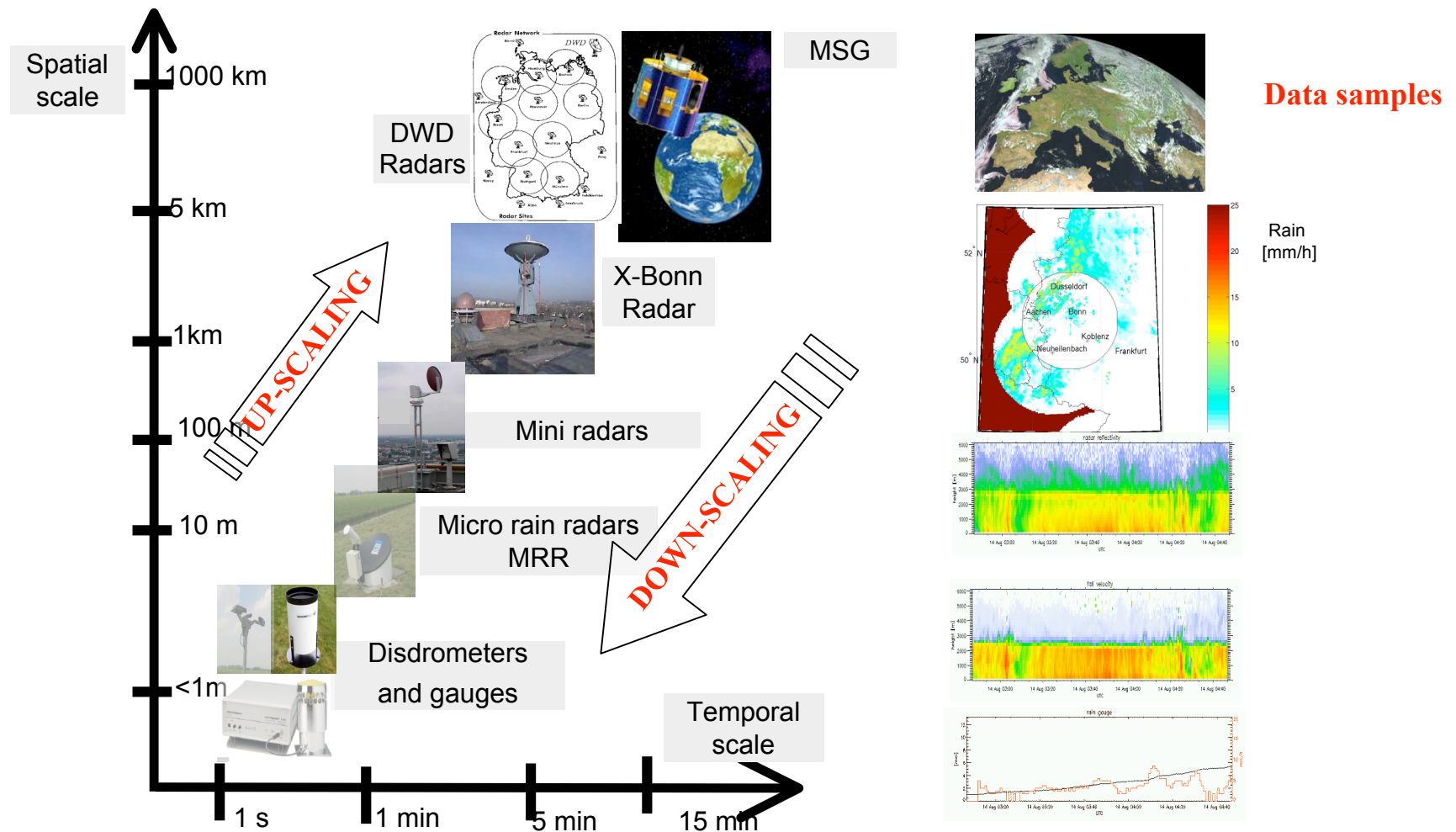


Goals of the project

Detection and monitoring of **structures and size distribution of rain-fields** covering **spatial scales from hundreds of metres to tens of kilometres and temporal scales from minutes to months** for the **Rheinland** (core observation tool=twin pol-X-band radars) → development of a **high-resolution multi-scale space-time precipitation model** from direct and remote sensing measurements

Long term **monitoring of total liquid water content** under all-weather-condition and its **partitioning into cloud and rain water** by polarimetric multi-wavelength radiometer

Issue n°1: rain spatio-temporal variability

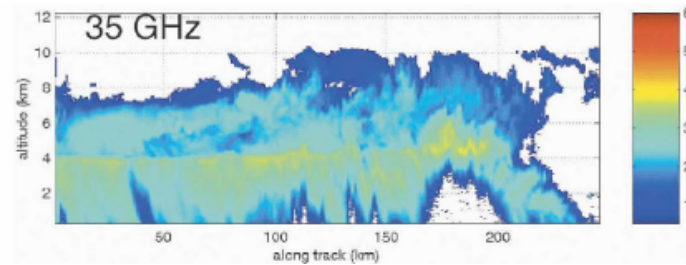
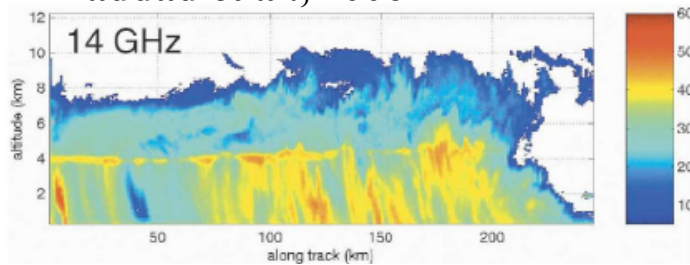


Rain fields are highly variable in space and time → need for multi-scale observations and up/downscaling methodologies. Drop size distribution fields mirror this high spatio-temporal variability as well.

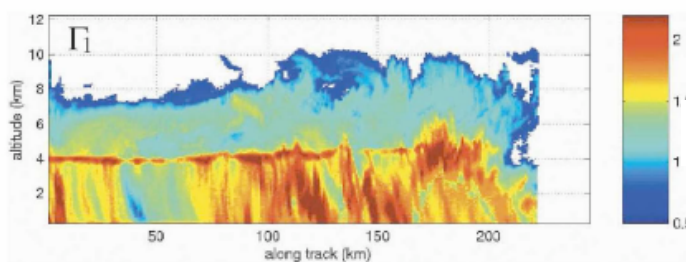
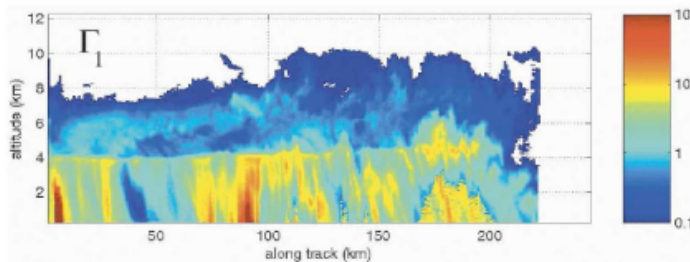
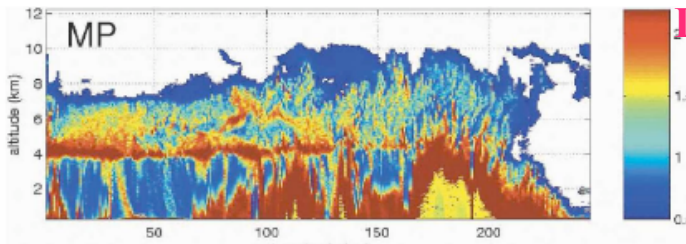
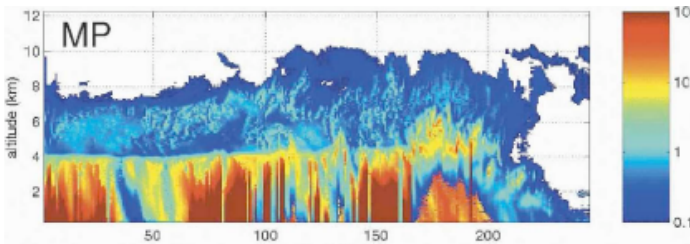
Unfastening the DSD Gordian knot?

Haddad et al., 2006

PR-2 overpasses



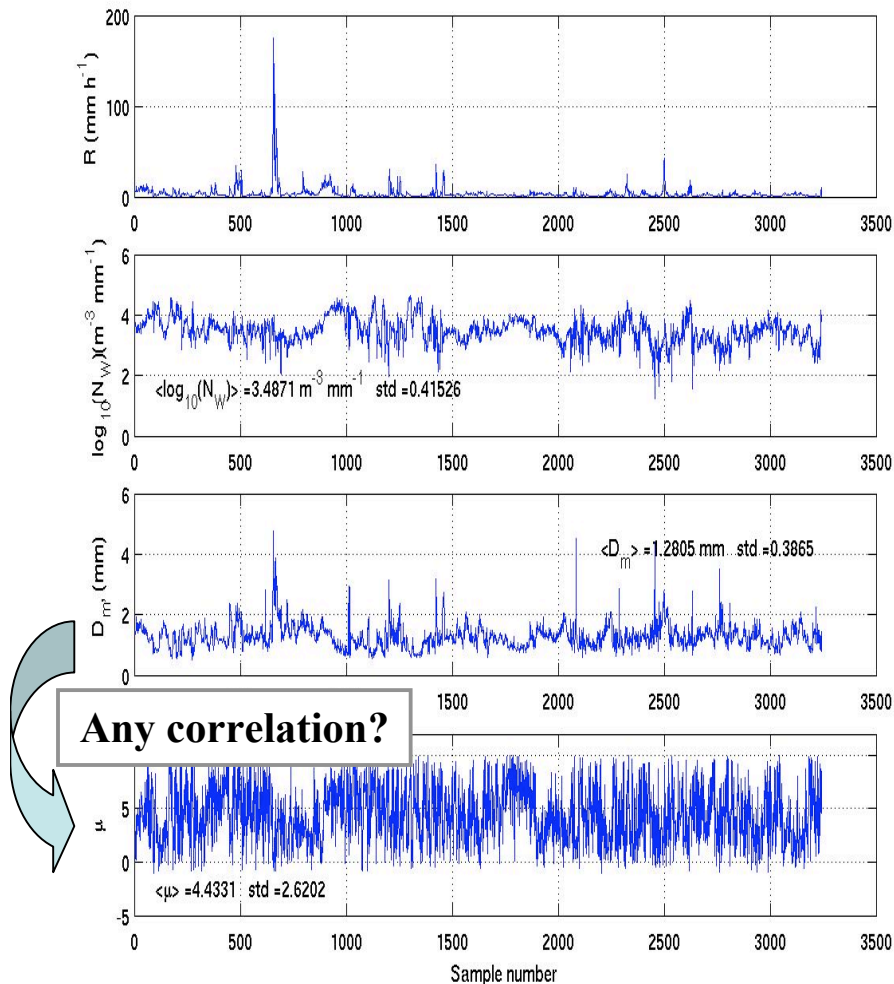
Reflectivity [dBZ]



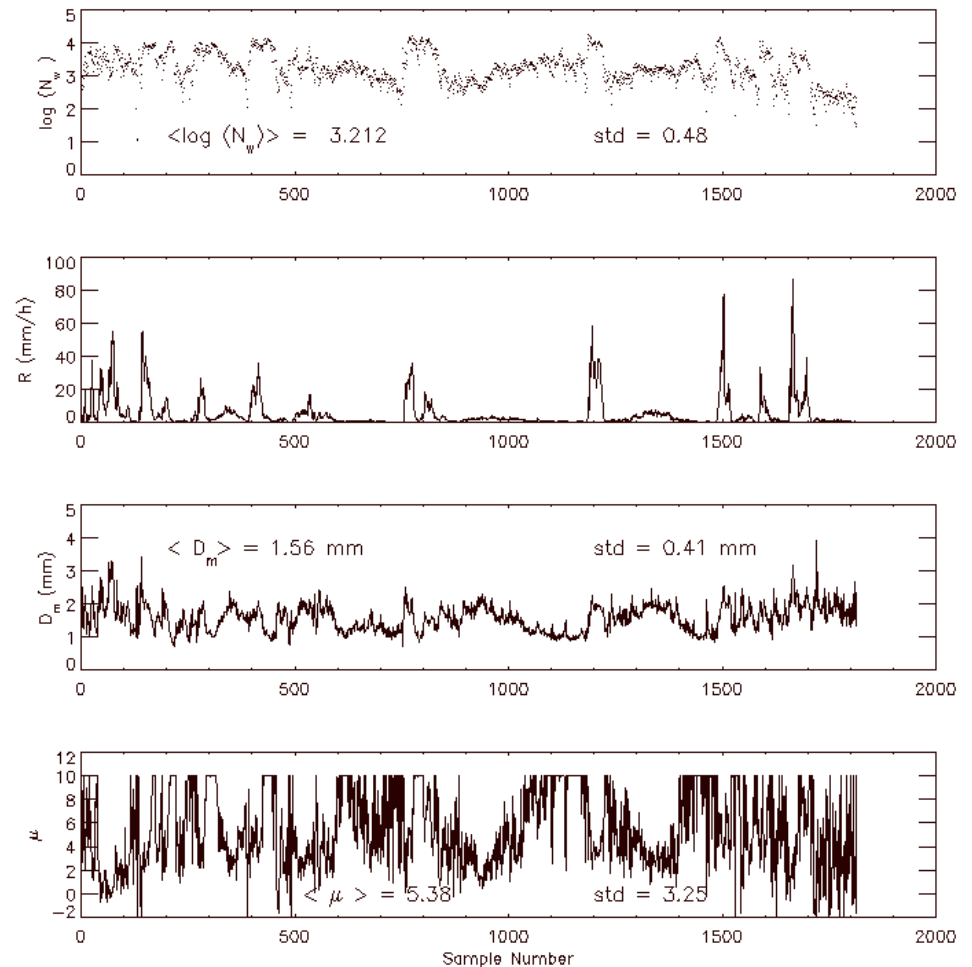
$$N(D) = N_0 D^\mu \exp[-\Lambda D] = N_0^* \kappa(D, \mu) \exp\left[(-3.67 + \mu) \frac{D}{D_0}\right]$$

Even a **dual-wavelength radar algorithm requires DSD assumptions**. The goodness of the retrieval relies on the quality of the a-priori knowledge (vertical and horizontal variability of DSD parameters).

DSD: a priori from disdrometer measurements



More than one-year from Bonn



2006 Rainy season in Benin (courtesy P. Zahiri)

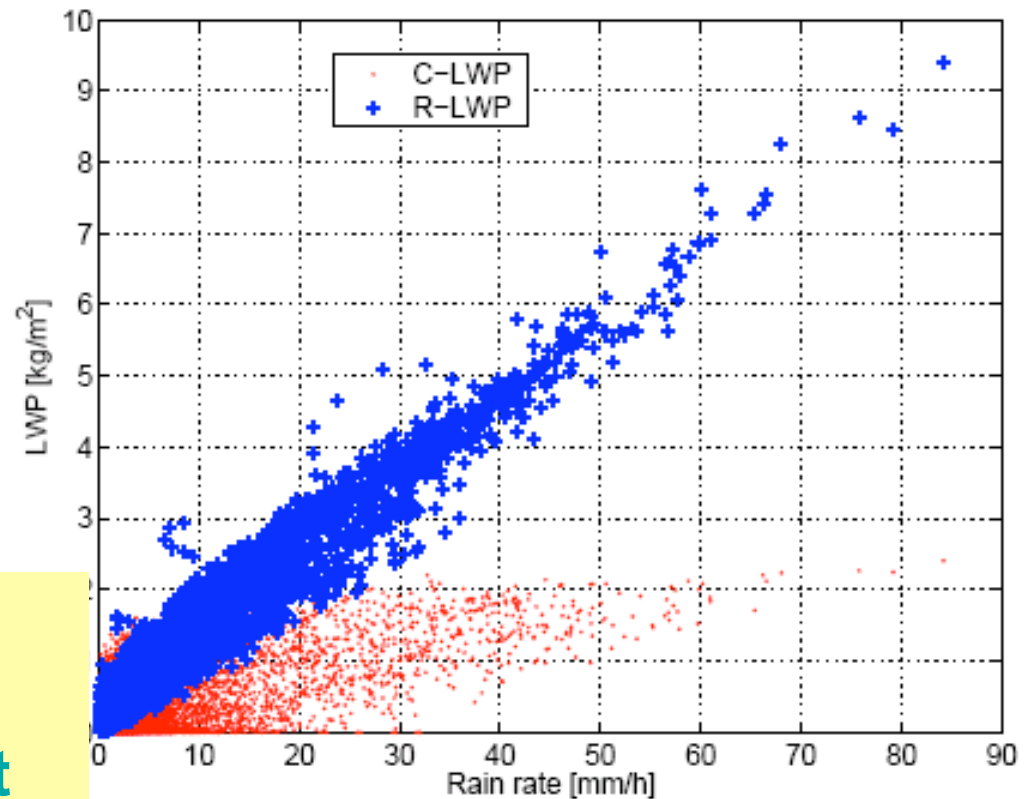
Can we better constrain the a-priori covariance matrix for SDS parameters in order to improve the rain retrieval? How does this depend on the spatial resolution?

Issue n°2: rain-cloud partitioning

Can we measure cloud and rain water contents simultaneously?

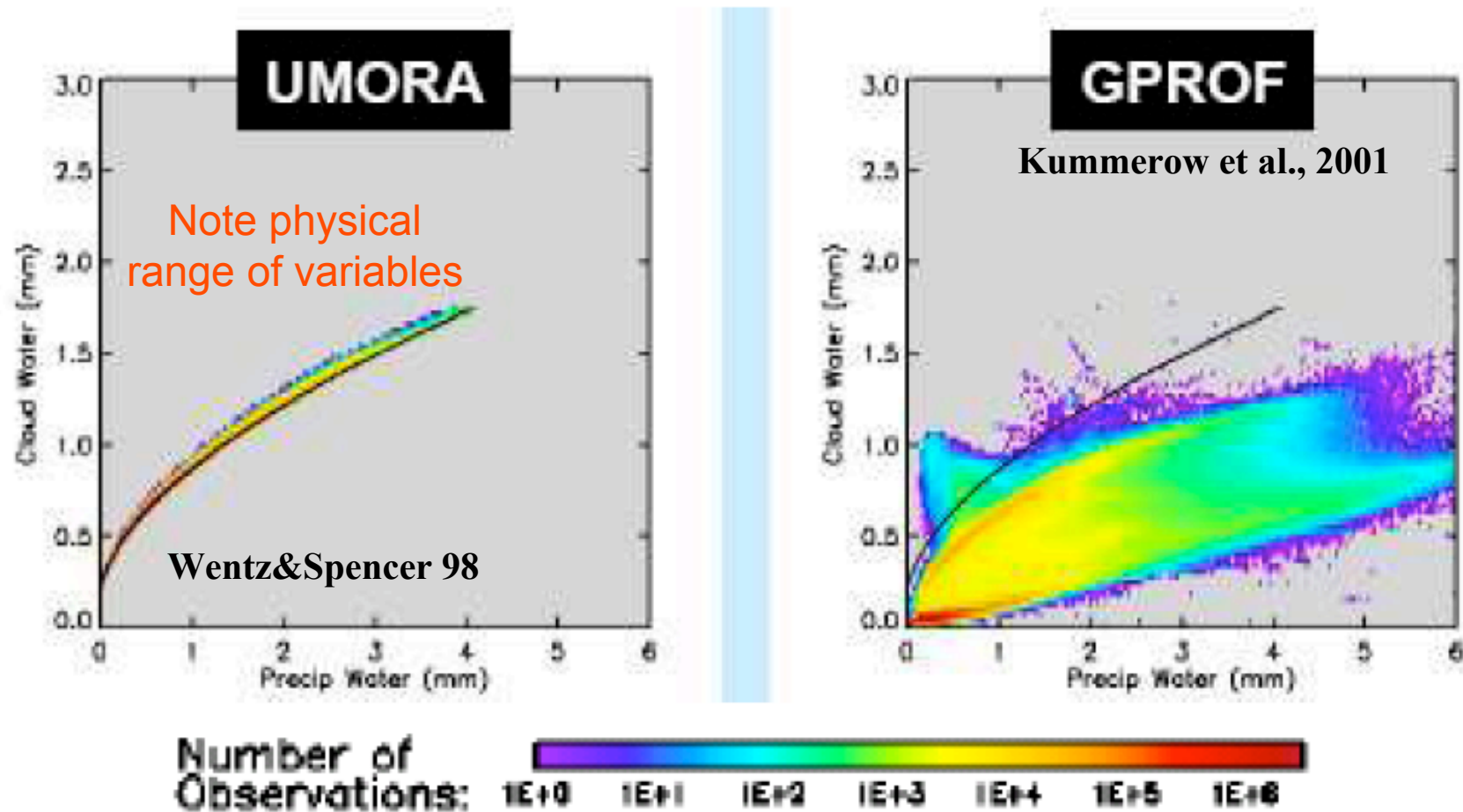
At the moment the partitioning between cloud and rain is predicted only from cloud models

But are cloud models correct?
Do they predict the right rain efficiency?



MidAtlantic Cold Front Simulation
from the GCE

Relevance in PMW rain retrieval



Partitioning between integrated cloud and precipitable water in two different **passive microwave** rain retrieval algorithms → different TBs for the same rain-LWP

Relevance in radar-based rain retrieval

- CloudSat deploys a W-band radar (as EARTHCare);
- GPM mission will exploit a double-frequency X-Ka system

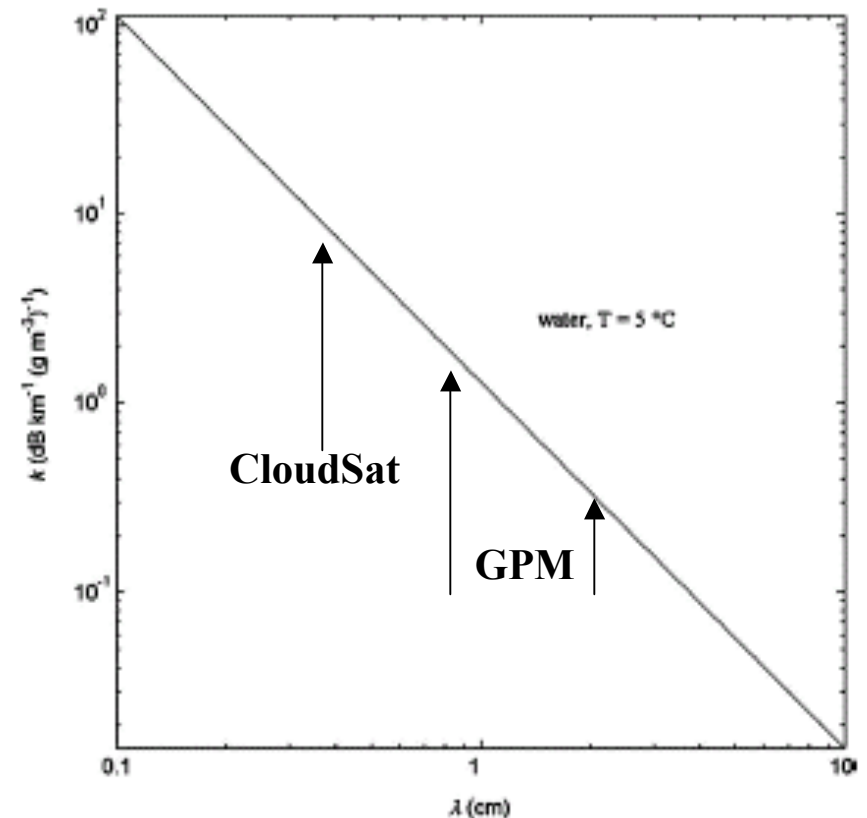
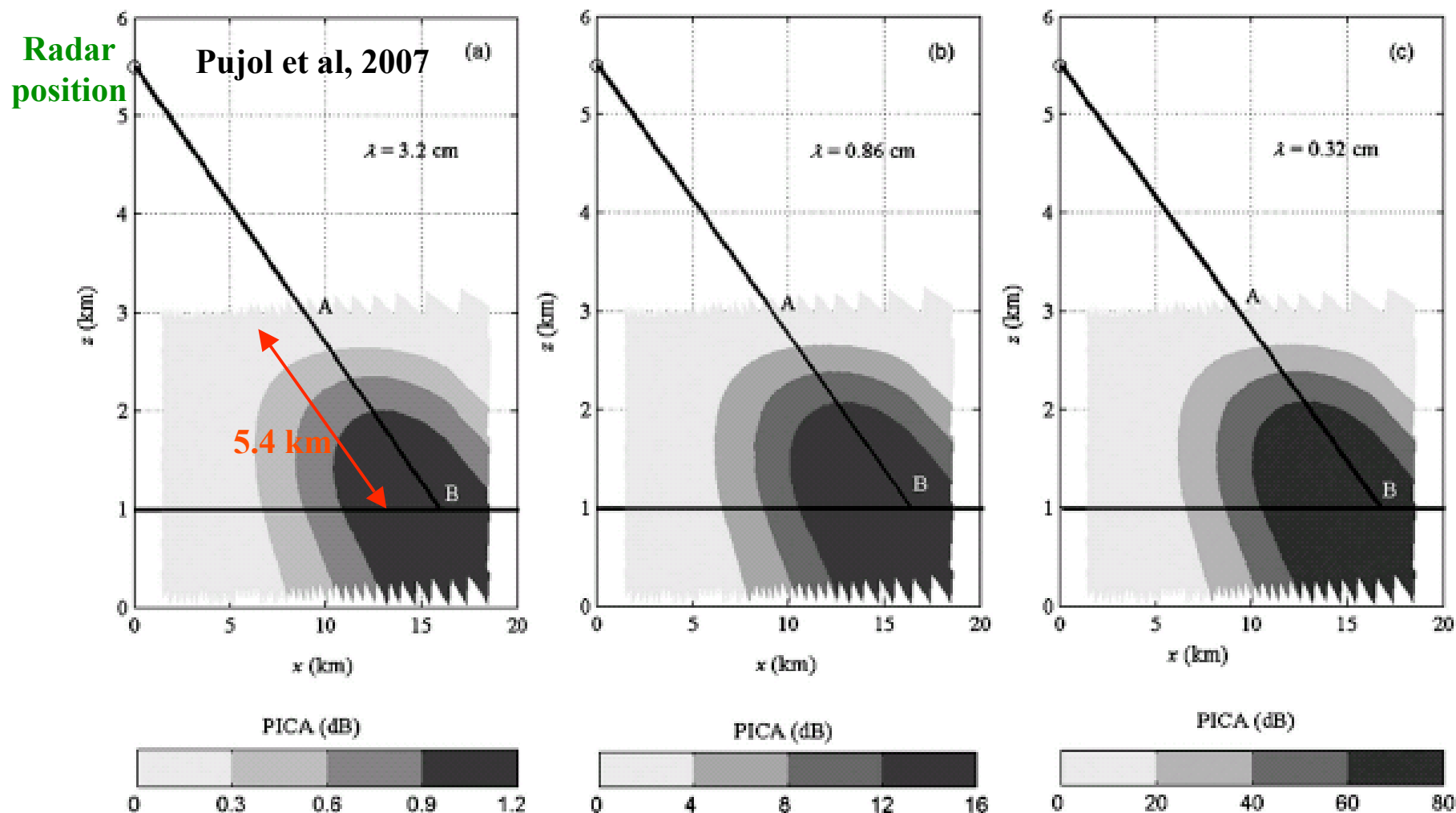


FIG. 5. Two-way cloud attenuation k as a function of the radar wavelength λ for a cloud liquid water content equal to 1 g m^{-3} and a droplet temperature of 5°C .

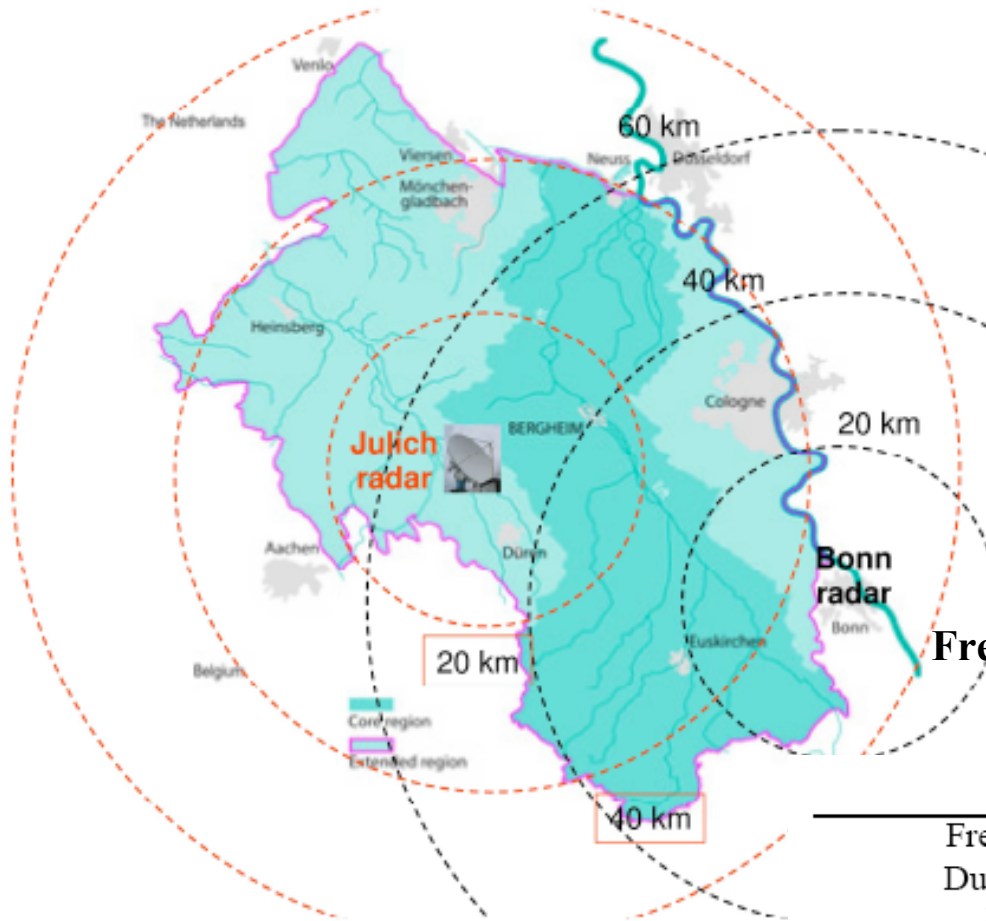
Liquid water content has a key role in attenuation at large frequencies (K_a , W band), despite its almost inefficacy to backscatter radiation (proportional to sixth power): stratocumuli, nimbostrati and cumuli have reflectivities respectively in the range $-50/-20 \text{ dBZ}$, $-45/-17 \text{ dBZ}$, $-37/0 \text{ dBZ}$.

Attenuation due to LWC



Path integrated cloud attenuation can strongly reduce the signal at high frequencies (K_a , W band)

Resources I: the twin pol X-band radars



A **twin 200 kW X-band** system is under construction at EEC.

Expected delivery time:

Bonn radar (funded by Transregio) → before the summer

Julich radar (funded by TERENO) → end of the year

Free scanning strategy → volume scans for CFADs

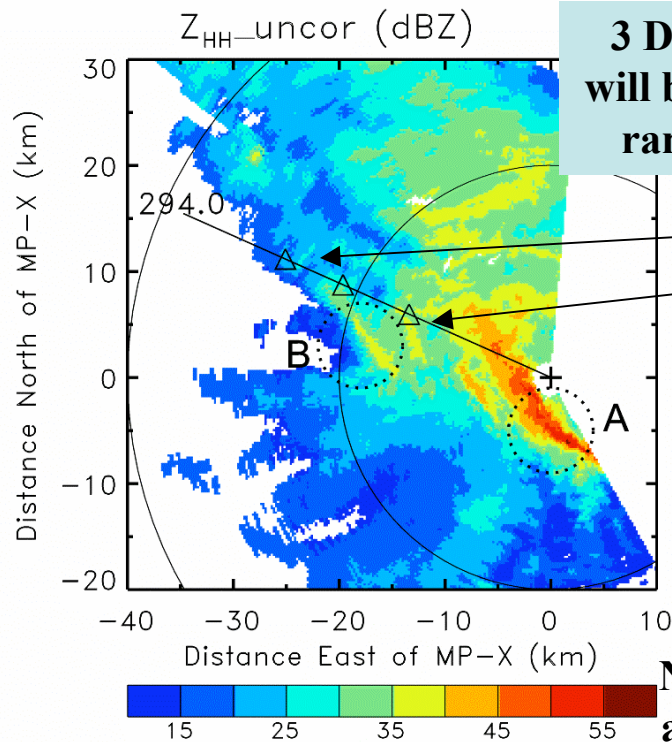
Key parameters driving the horizontal resolution
(@10 km 30x170m²)

Time resolution approximately equal to revolution time ≈ 1 minute

Table 1: Characteristics of the X-band radars.

Frequency	9.3 GHz	3cm
Duty cycle	0.0011	
PRF	250 – 2500 Hz (within the duty cycle)	
Pulse duration	0.2, 0.5, 1.0 μm	
Antenna beam-width	< 1°	
Antenna gain	44.5 dB	
Side lobes	> -26 dB down from main lobe @ ≤ 12°	
Minimum detection signal	> -114 dBm	
Minimum detection range	200 m	
Dynamic range	> 100 dB	
System clutter rejection	> 46 dB	

Additional rain measurements



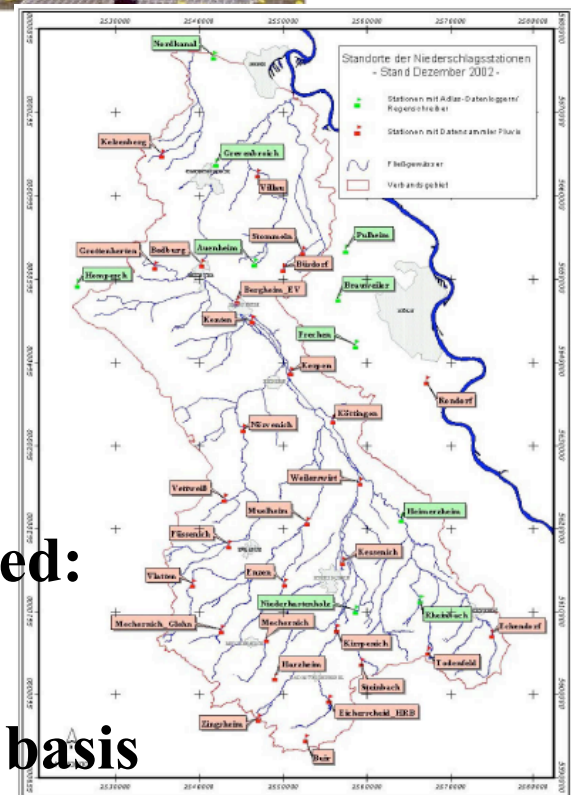
3 DSD-measuring units
will be located at different
ranges from the radar



Micro rain radar



Network of 32 rain gauges
and 26 flow measurements
(Erft catchment)



The DSD point-like measurements can be used:

❑ to validate the rain product

❑ to modify the a-priori on a storm-to-storm basis

Resources II: ADMIRARI

(**AD**vanced **MI**crowave **RA**diometer for **R**ain **I**dentification)

RPG-6CH-DP

10.65 / 21.00 / 36.5 GHz

(V/H pol.)

- **direct detection**
- **full internal calibration**
(Dicke switch / Noise Injection)
- **Fully steerable in zenith and azimuth**
- **Water-repellent coating on the antennas**
- **5 degrees beam-width**

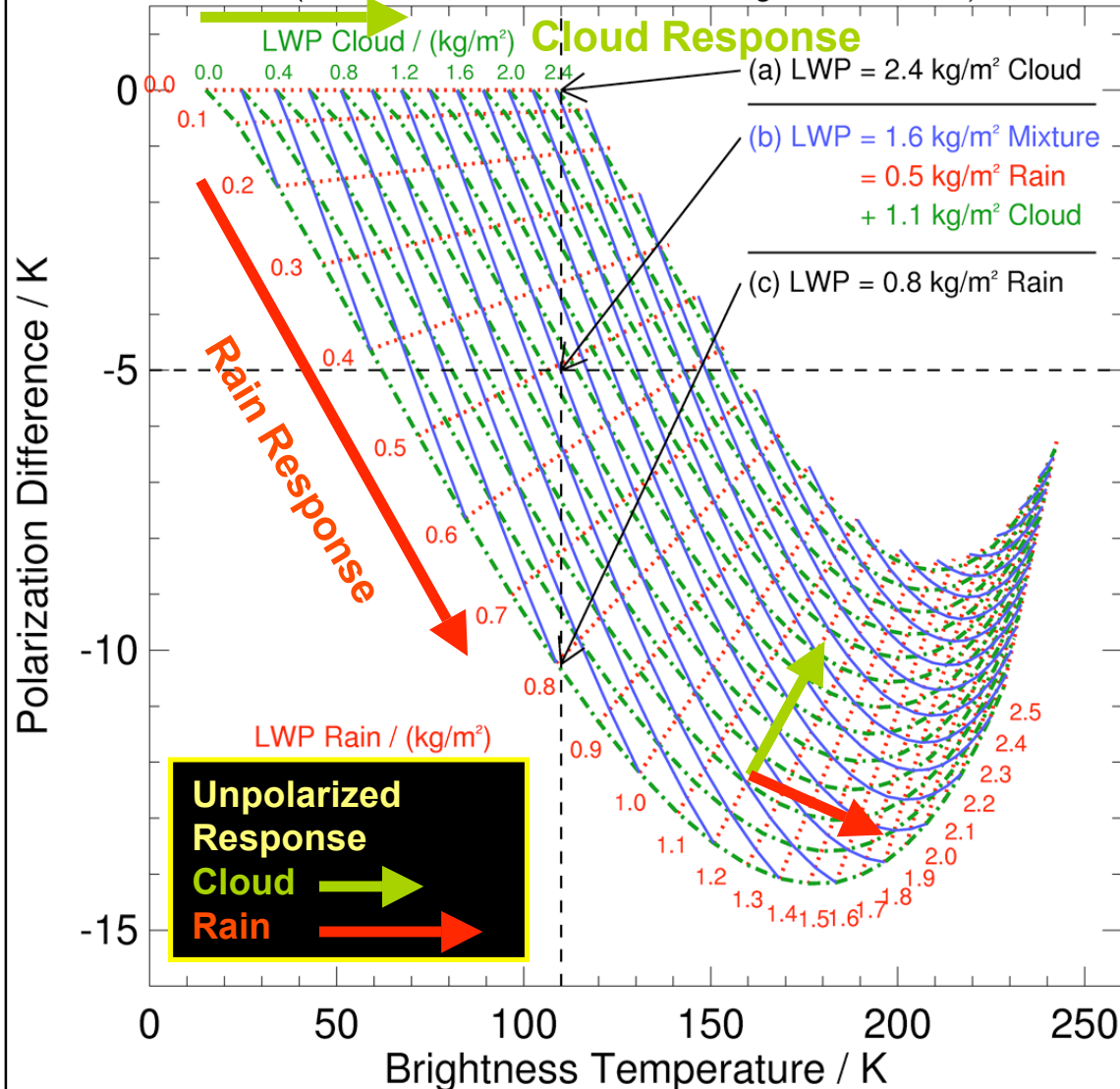
Funded by DFG



Proposed Retrieval Method

Czekala et al, Geophys. Res. Lett. 28 (2), 267–270, 2001.

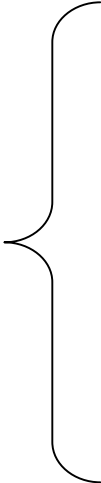
Combined TB/PD Response of Different LWP Compositions
(Model at 19.0 GHz and 30.7 Degrees Elevation)



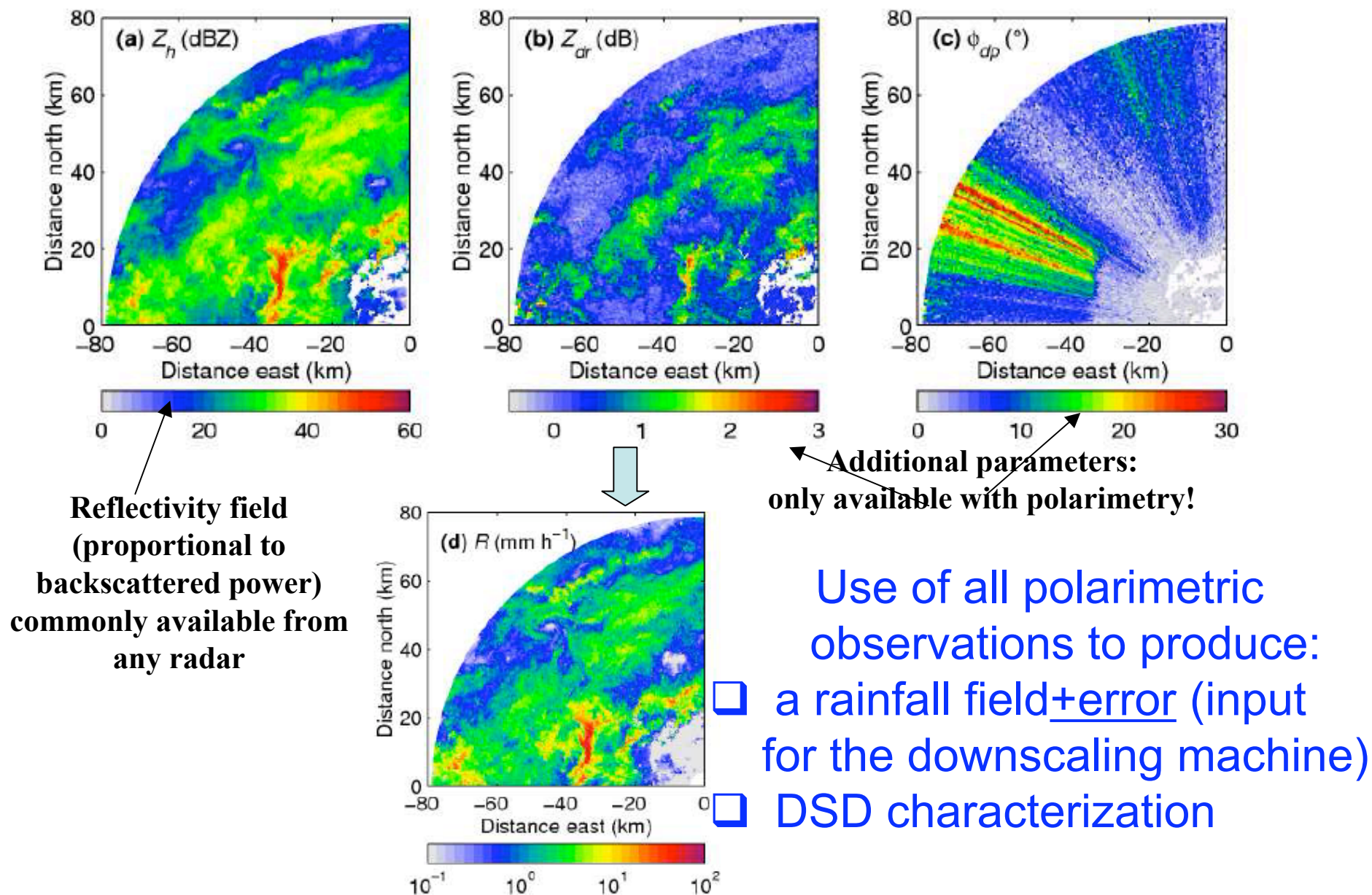
- Along **red** lines:
rain LWP constant, increasing cloud LWP (left to right)
- Along **green** lines:
cloud LWP constant, increasing rain LWP (top to bottom)
- Along **blue** lines:
total LWP constant
- Simultaneous measurement of brightness temperature and polarization difference
- Independent retrieval of cloud and rain fractions possible
- Accuracy of polarization measurement crucial
- Re-calibration with clear sky conditions

Methodology

1. Variability of DSD

- 
- a. Preparatory polarimetric studies
 - b. Validation of the RR-algorithm
 - c. Spatio-temporal structure of precipitation and DSDs
 - d. Data assimilation of polarimetric radar data

RR-algorithm



Optimal estimation technique

Idea: to retrieve the DSD parameters at n (≈ 100) different pixels of a whole radar ray

$$N(D) = N_0 D^\mu \exp[-\Lambda D]$$

unknown
s

$$X = \begin{pmatrix} D_{0,1} \\ \cdot \\ \cdot \\ D_{0,n} \\ \mu_1 \\ \cdot \\ \cdot \\ \mu_n \end{pmatrix}$$

$$Y = \begin{pmatrix} Z_{DR,1} \\ \cdot \\ \cdot \\ Z_{DR,n} \\ \phi_{DP,1} \\ \cdot \\ \cdot \\ \phi_{DP,n} \end{pmatrix}$$

measurements

N_0 derived from Z_h measurements

Cost function to be minimized

$$\sum_{i=1}^n \frac{(Z_{DR,i} - Z'_{DR,i})^2}{\sigma_{Z_{DR}}^2} + \frac{(\phi_{DP,i} - \phi'_{DP,i})^2}{\sigma_{\phi_{DP}}^2} + \frac{(x_i - x_{a,i})^2}{\sigma_{x_a}^2}$$

Error in the a-priori estimate

A priori estimate

Optimal estimation technique

The solution is found by using a Newtonian iteration

$$\mathbf{x}_{k+1} = \mathbf{x}_k + \mathbf{A}^{-1} [\mathbf{H}^T \mathbf{R}^{-1} \delta \mathbf{y} - \mathbf{B}^{-1} (\mathbf{x}_k - \mathbf{x}^a)]$$

Error covariance matrix of observations/a priori

Forward model

$$\mathbf{A} = \mathbf{H}^T \mathbf{R}^{-1} \mathbf{H} + \mathbf{B}^{-1}$$

$$\delta \mathbf{y} = \mathbf{y} - H(\mathbf{x})$$

$$H = \begin{pmatrix} \frac{\partial Z_{dr,1}}{\partial D_{0,1}} & \dots & \frac{\partial Z_{dr,1}}{\partial \mu_n} \\ \cdot & & \cdot \\ \frac{\partial \phi_{DP,n}}{\partial D_{0,1}} & \dots & \frac{\partial \phi_{DP,n}}{\partial \mu_n} \end{pmatrix}$$

Key component=Jacobian matrix

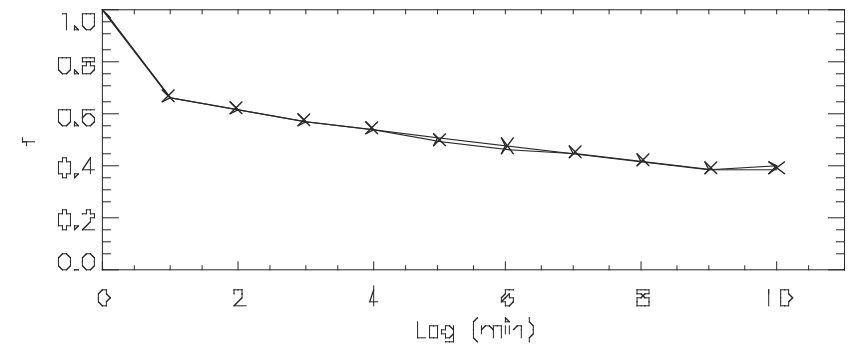
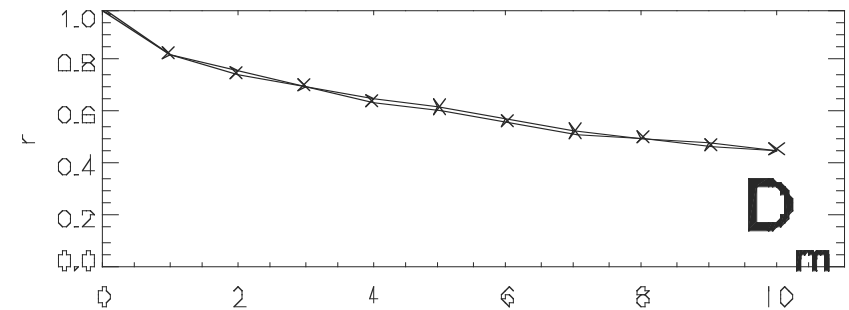
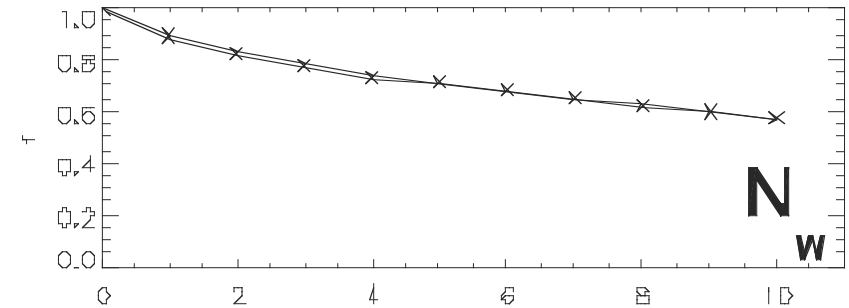
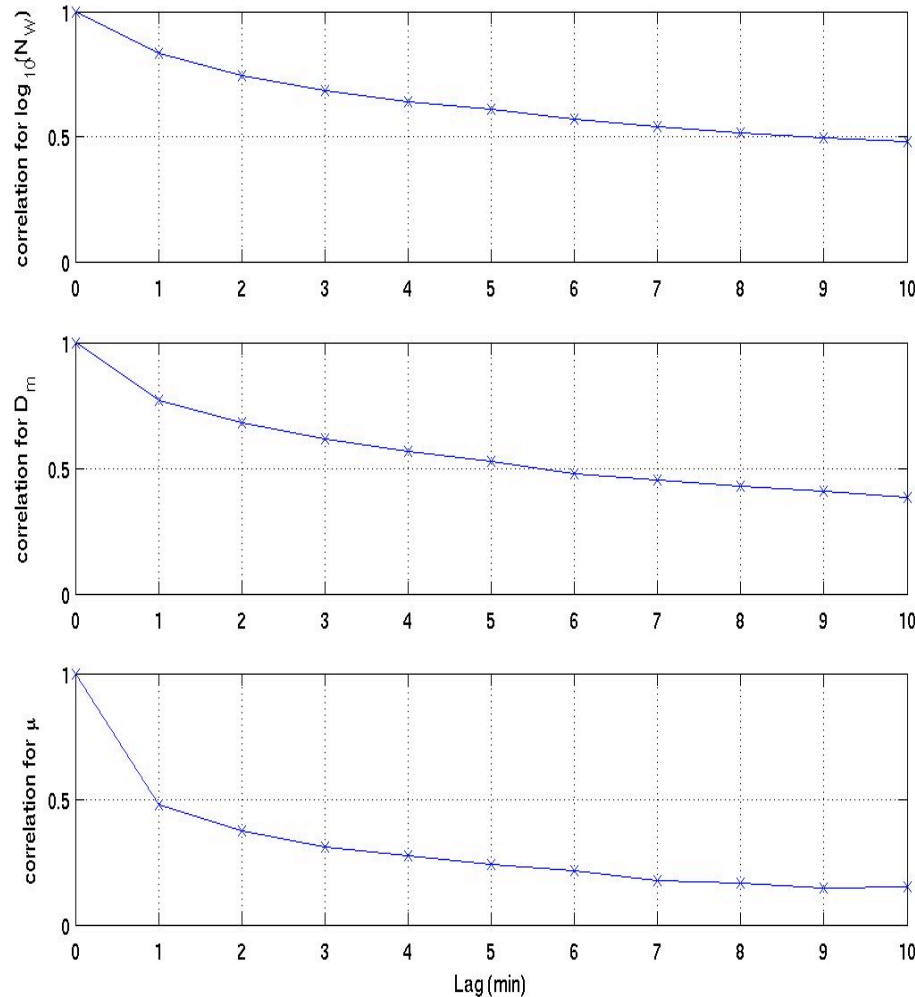
Covariance matrix of the retrieved parameters

$$S_X = \left(B^{-1} + H_i^T R^{-1} H_i \right)^{-1}$$

accounts for the error in the measurements and in the a-priori knowledge

Building the a-priori covariance matrix B

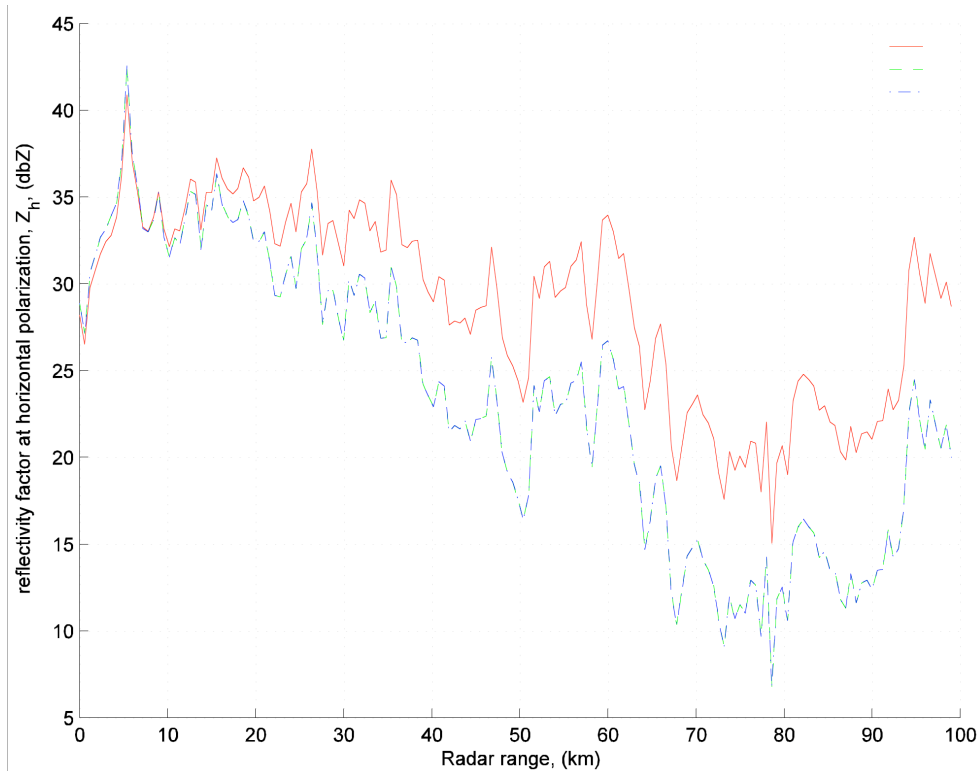
Which is the spatial correlation of DSD parameters?



We can use Taylor assumption to convert temporal into spatial correlation

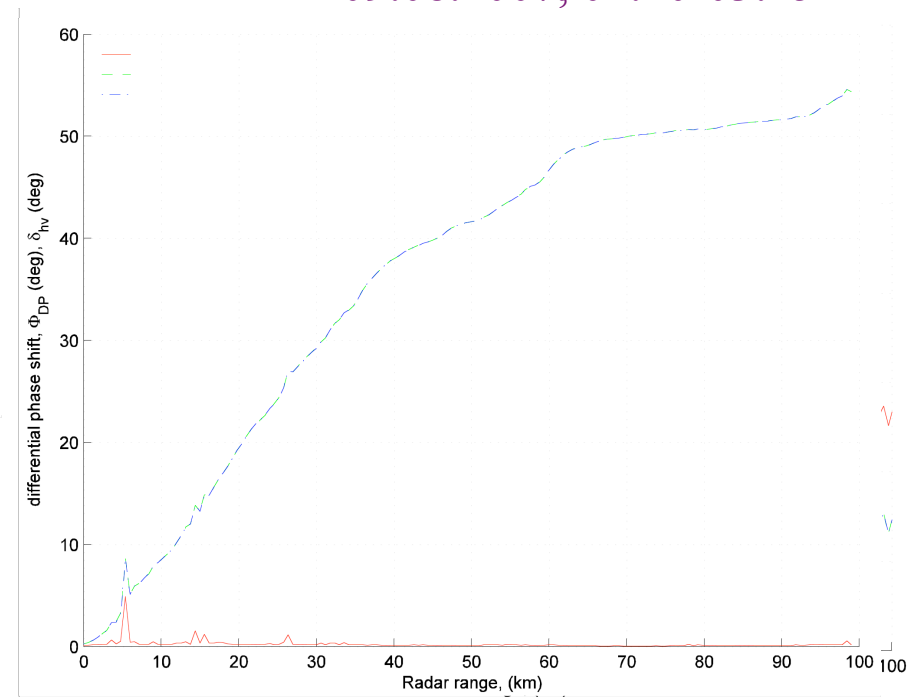
Forward model

Look-up tables of single scattering properties have been computed by T-matrix → extremely fast to simulate any polarimetric radar variable

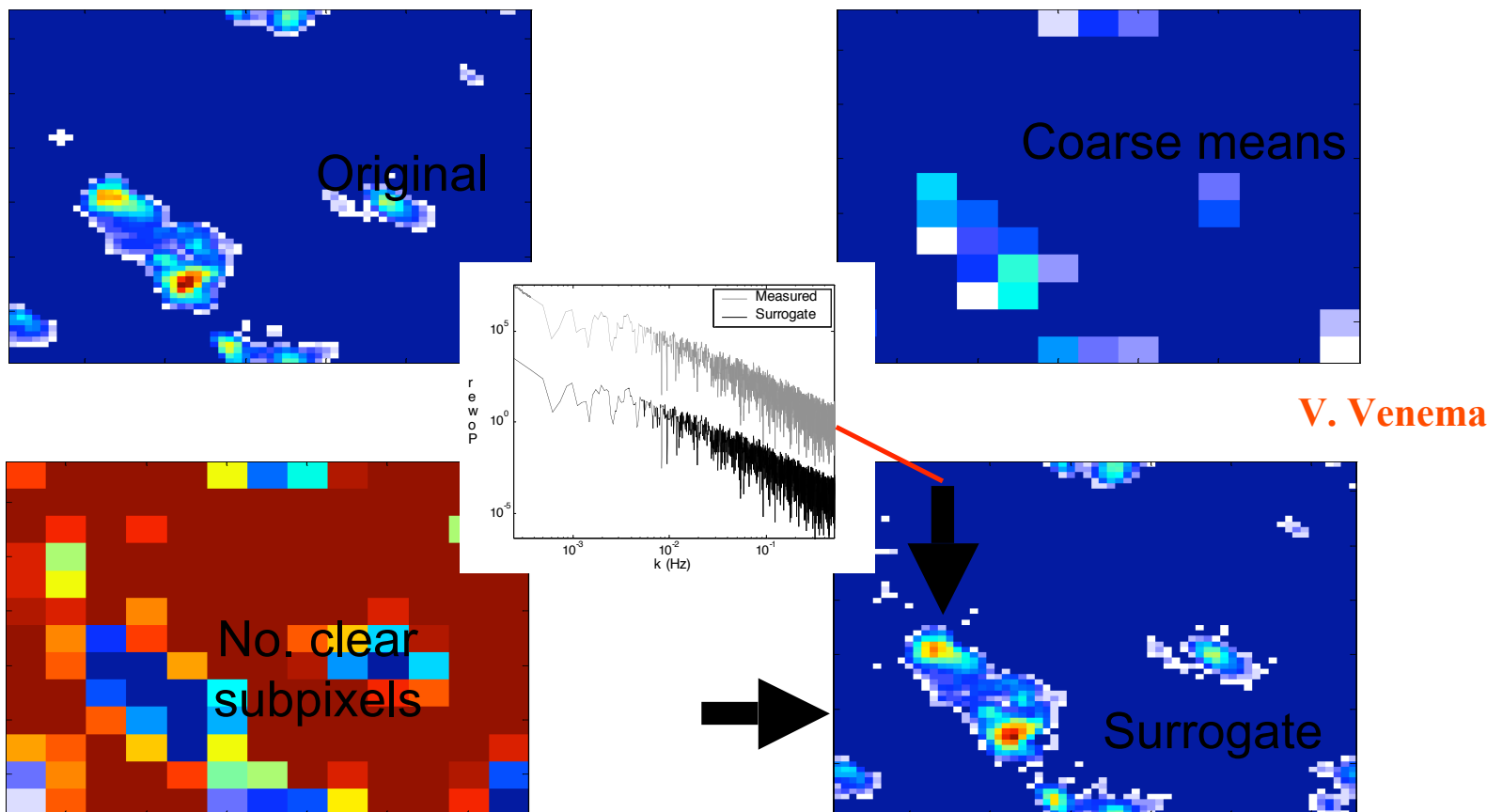


effective (from spectrum DSD)
measured (from spectrum DSD)
measured (from Gamma DSD)

Based on DSD data of
09.08.2007, 01:10-03:45



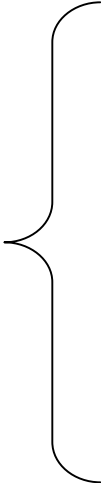
Downscaling methodology: an example with a cumulus field




1. Iterative Amplitude Adapted Fourier Transform (IAAFT) → downscaling
2. Multilevel Statistical Objective Analysis (MLSOA) → assimilation of uncertain and sparse surface precipitation estimates
3. Merging of IAAFT with MLSOA (combined methodology)

Methodology

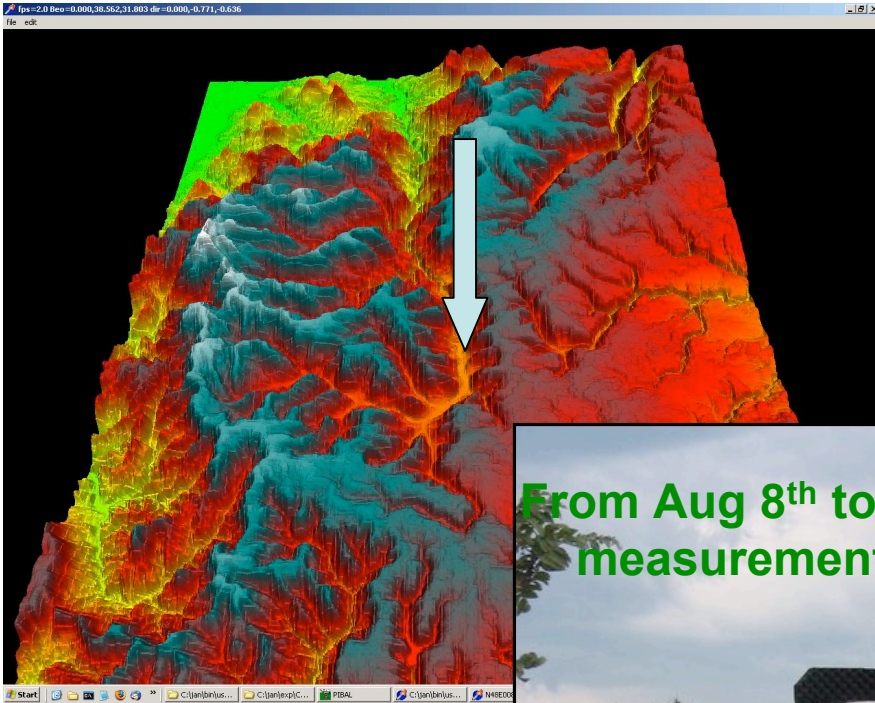
1. Variability of DSD

- 
- a. Preparatory polarimetric studies
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2. Ancillary PMW polarimetric studies

- 
- a. Field measurements
 - b. LWP-Retrieval algorithm
 - c. Cloud modeling validation

COPS Field campaign



Heselbach im
(Schwarzwald)

COPS: Convective
induced P

From Aug 8th to Dec 19th continuous
measurements at their AMF site

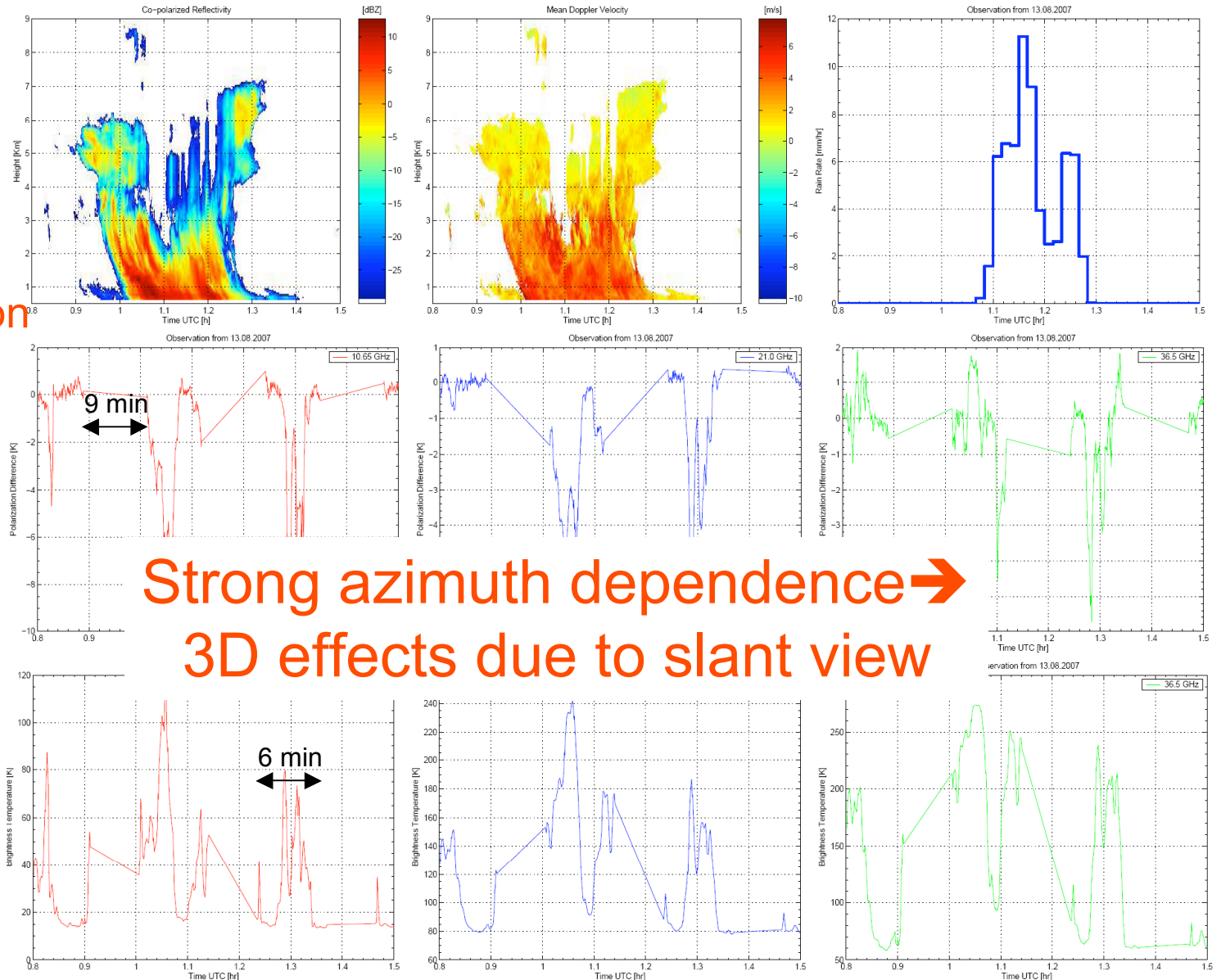


Supersite M:
Mobile Facility (AMF)

Case study: 13 August

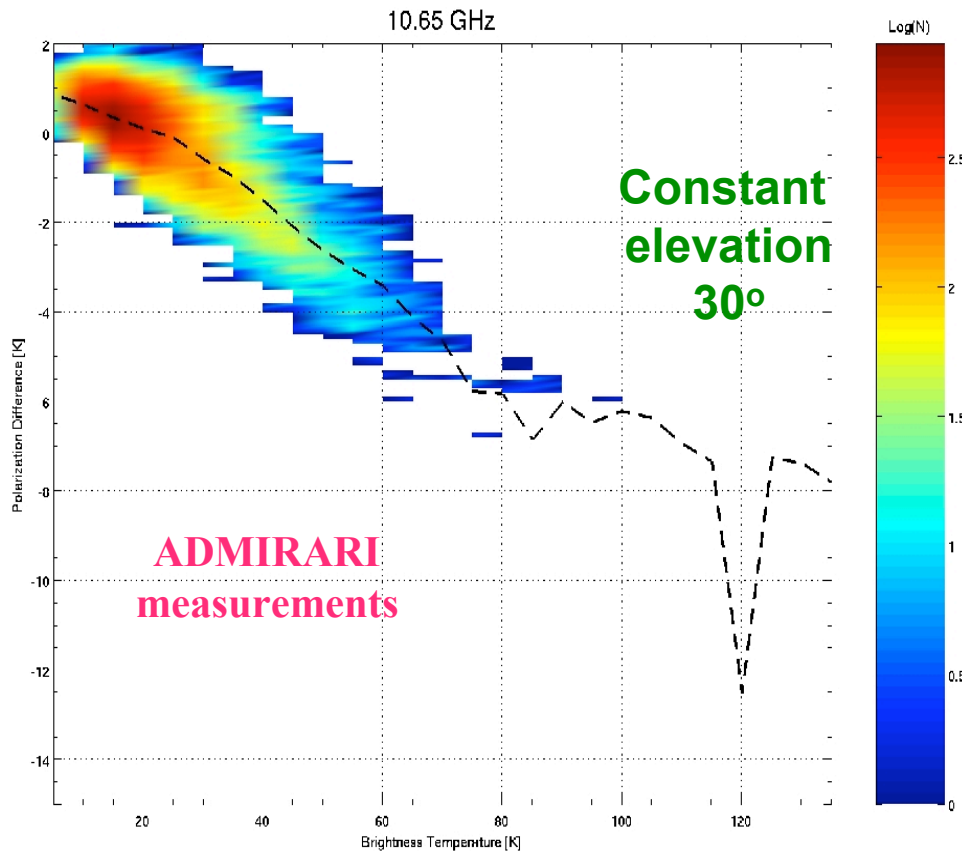
Constant elevation
scans @ 30°

Signal in advance
and delayed
compared
to AMF site →
3km rain layer
@30° corresponds
to a 5 km radius



Strong azimuth dependence →
3D effects due to slant view

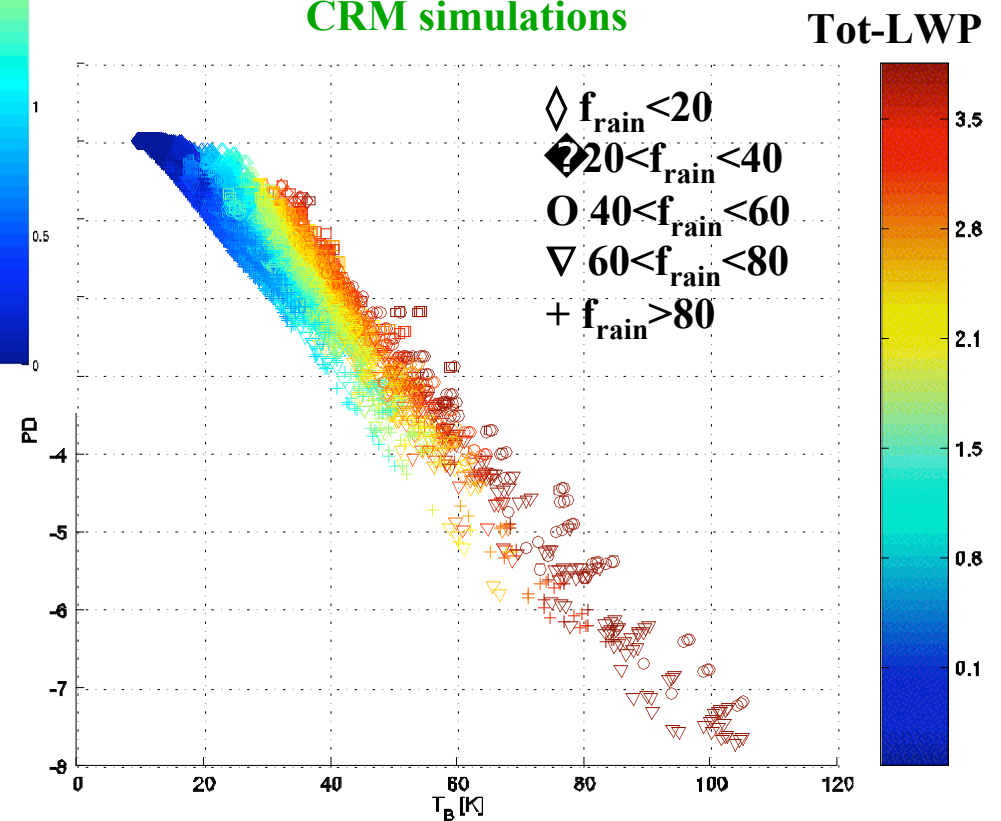
Rainy cases: global analysis



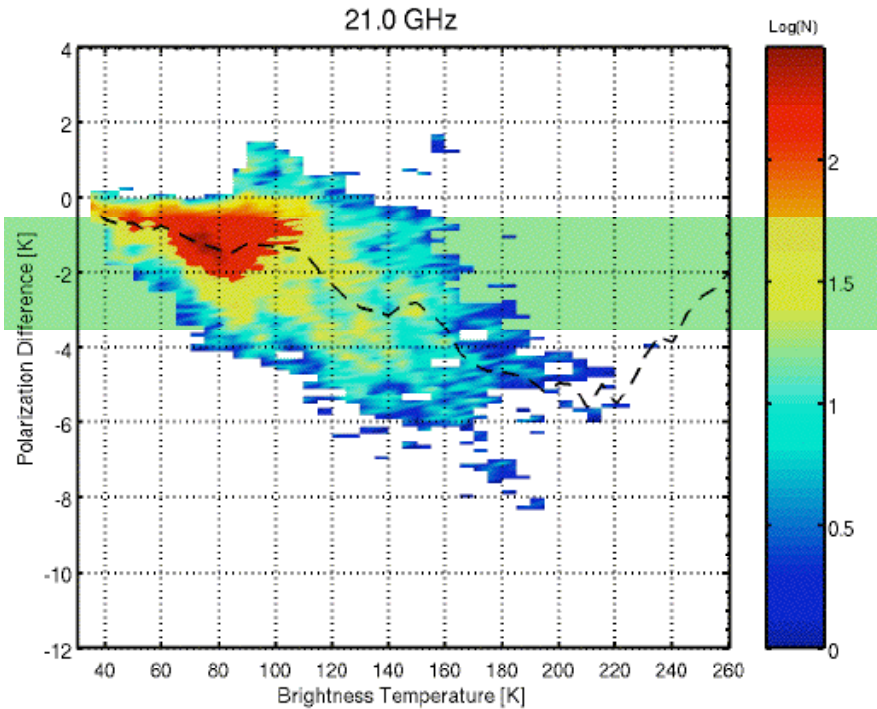
Radiative transfer simulation account
for the 3D effect due to the slant
viewing of the radiometer

COSMO model runs for the Black Forest with
resolution of 2.8 km have been used

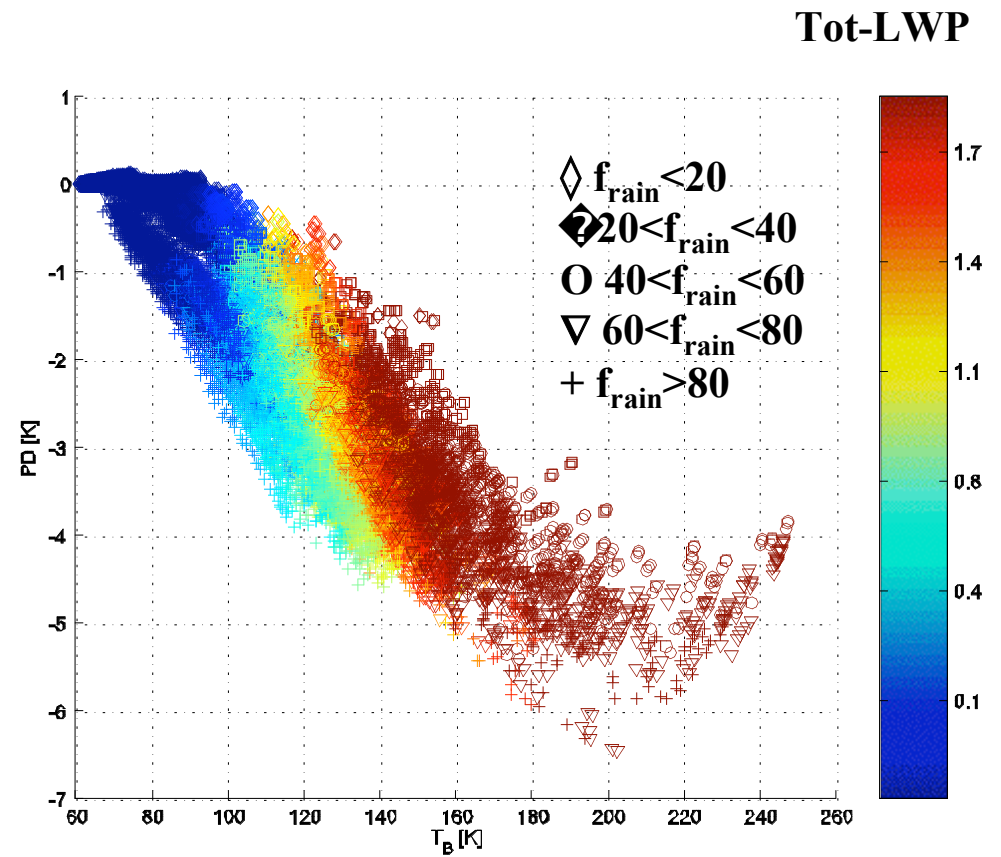
CRM simulations



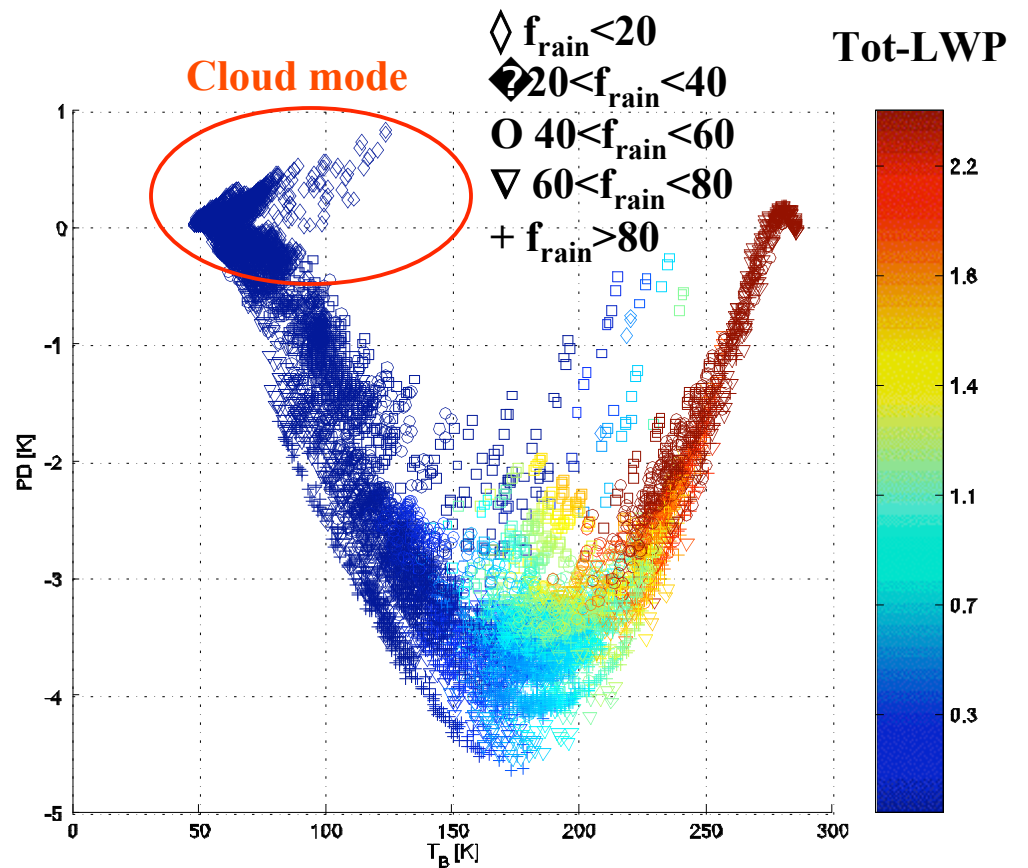
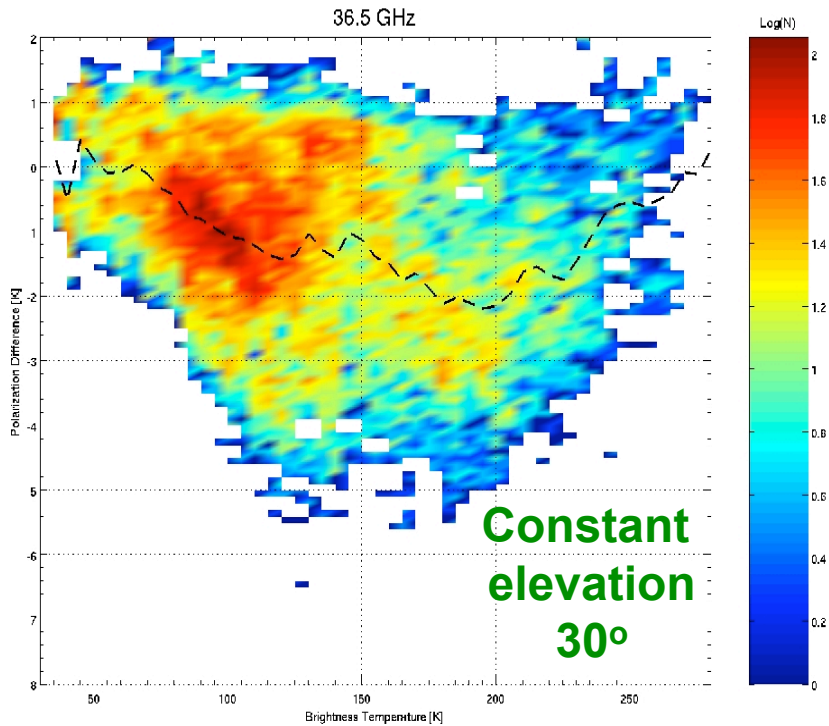
Rainy cases 21.0 GHz: global analysis



The average PD for a 5 K TB bin are showed as dashed lines.



Rainy cases 36.5 GHz: global analysis



Work plan

Task	Subtask	Time [months]
<i>X</i> –band radar polarimetry one 4-year PhD student	Preparatory polarimetric studies	$T_0 - T_0 + 12$
	Validation of the algorithm	$T_0 + 12 - T_0 + 24$
	Spatio-temporal structure of precipitation and <i>DSDs</i>	$T_0 + 24 - T_0 + 36$
	Data assimilation of polarimetric radar data	$T_0 - T_0 + 36$
Passive microwave polarimetry one 3-year PhD student	Field measurements	$T_0 - T_0 + 36$
	Retrieval algorithm development	$T_0 - T_0 + 12$
	Cloud modeling validation	$T_0 + 12 - T_0 + 36$

Synergies with other in the GV community

- Student exchange program with Ali Tokay at GSFC on DSD thematic
- Cooperation with CSU people (T. L'Ecuyer and J. Haynes) on snow and rain CloudSat product
- Cooperation with JPL people (S. Tanelli and S. Kobayashi) on multiple scattering evaluation.

Work in progress

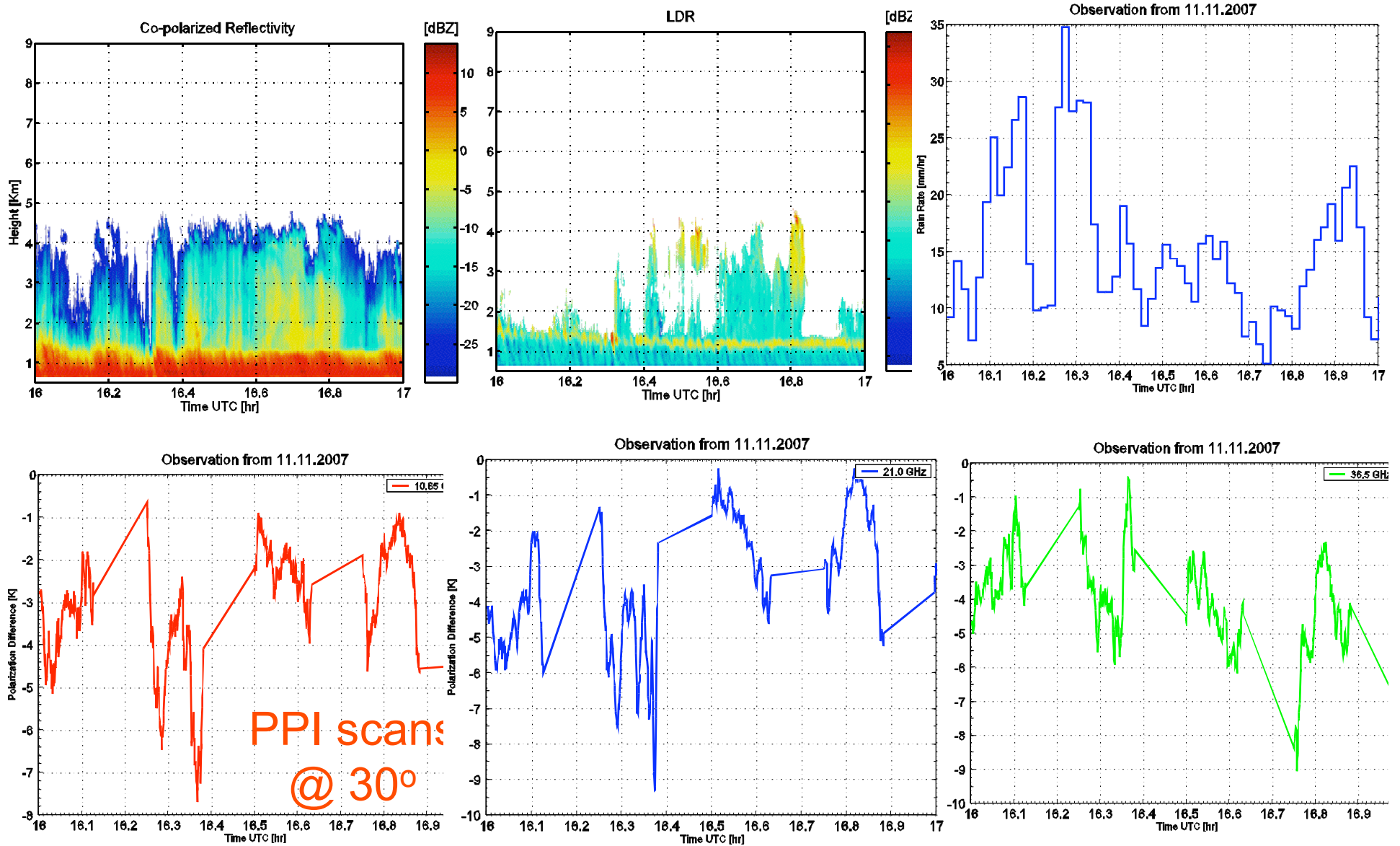
- ❑ Preparation polarimetric studies via disdrometer observations
- ❑ Development of retrieval algorithms for the separation of rain and liquid water path
- ❑ Participation to different field campaigns with operation of the three wavelength polarized radiometer in synergy with other active and passive instruments (EUCAARI next month) → availability to participate at other field campaign from October 2008

Paper on the topic are available at

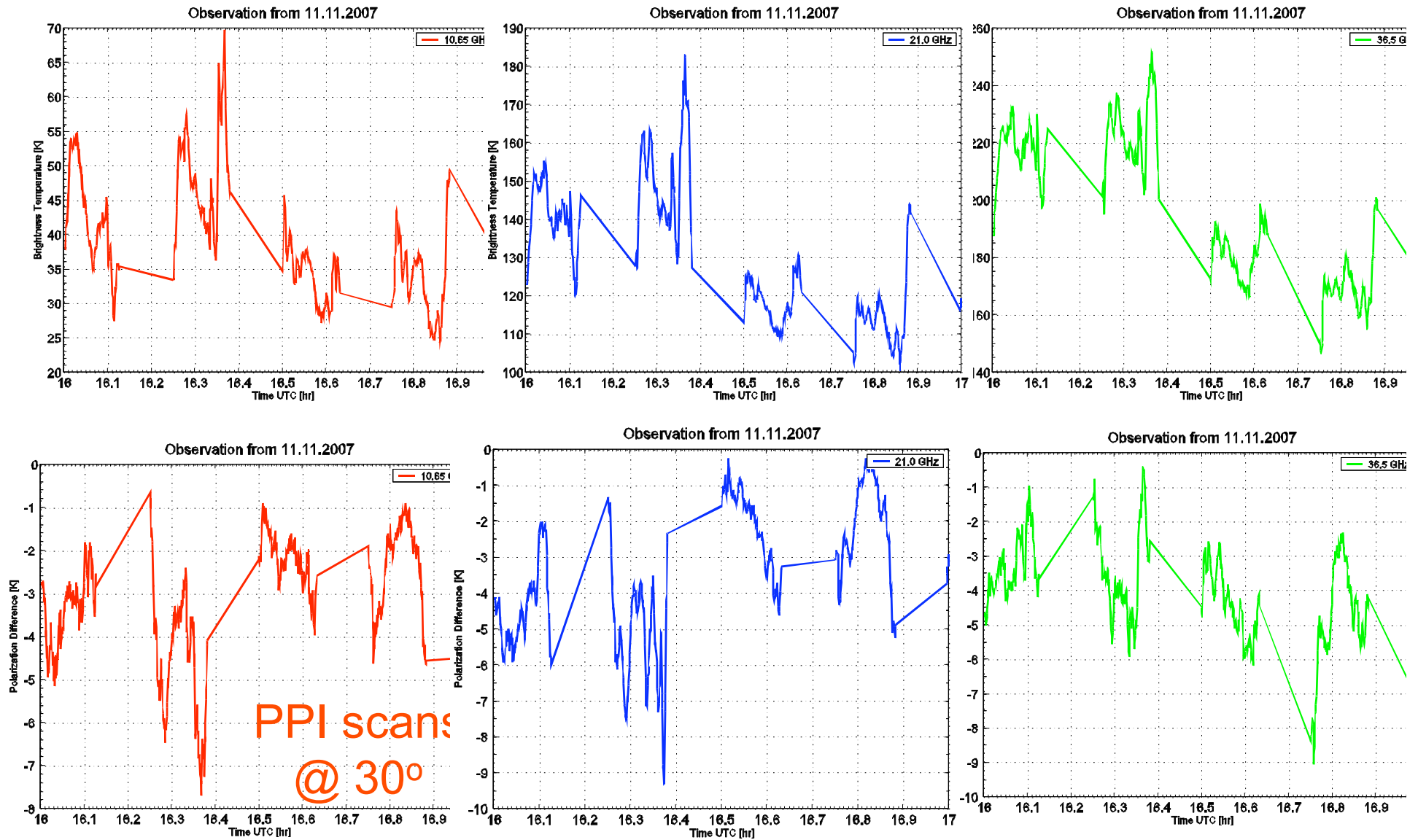
<http://www.meteo.uni-bonn.de/mitarbeiter/battaglia/index.html>

Back-up slides

Case study: 11 November



Bright band case:11/11

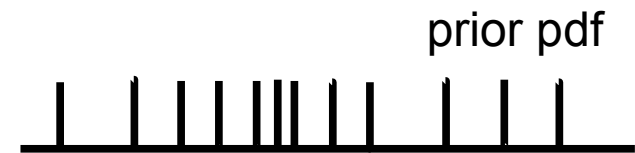


Particle filtering I

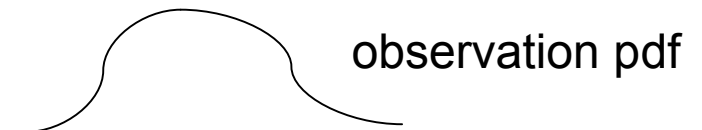
Basic Idea:

Apply a filter to correct a model state by observations, suitable for non-linear and/or non-Gaussian applications.

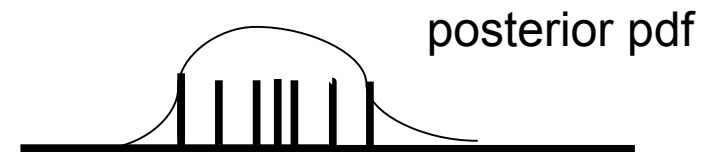
1. sampling step - generation of realizations by using an ensemble run



2. importance step - attach weights to the individual ensemble members utilizing the available observations



3. resampling step - re-sample the ensemble according to the given weights.



Particle filtering II

COSMO-DE Ensemble

Particle filter will be based on an ensemble of model forecasts,

A larger number of members may be created and a removal of most probably unsuccessful members may be based on few prognostic steps without disturbing too much the produced PDF

Radar Network

Observations itself can be used to generate an ensemble of predictions and apply the particle filter, where free parameters concerning initial track direction and intensity tendency will be varied within their respective range of uncertainty

First crucial steps for both: To estimate the probability (weights) of the forecasts depending on the variation of the free parameters.